PCT

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(54) Title: METHOD AT OFDM-RECEPTION FOR CORRECTION OF FREQUENCY, TIME WINDOW, SAMPLING CLOCK AND SLOW PHASE VARIATIONS
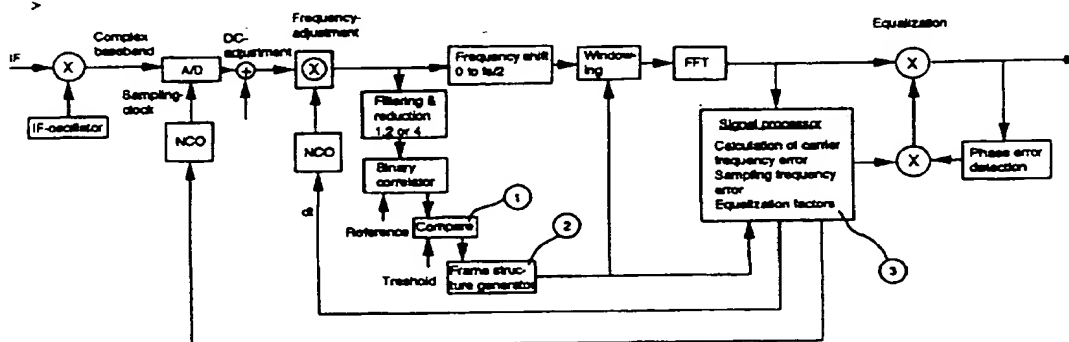
(57) Abstract

The present invention relates to a method for correction of frequency, time window error, sampling clock and phase error at OFDM-receivers. The information which is transmitted in a signal which includes several carriers in digital form, includes consecutive frames comprising a number of symbols. In respective frames at least one up-chirp and one down-chirp is arranged. Correction of the frequency is made based on analysis of the up- and down-chirps. Further the main focus of the weighted impulse response is determined. The position of the main focus is used for correction of the time window and the sampling clock. Further the vectors from the location of the received carriers are registred in relation to their ideal location in a matrix. The angles between the received vector and the ideally located vector are determined and are weighed together with regard to the amplitude of the transmission function at the frequency of the carrier and the distance of the vector to the origin of coordinates. An average is after that made of the weighed angle distances. The obtained average is used for correction of the phase error. Further, the knowledge of the obtained phase error and previous phase errors is used for estimation of the coming phase error in the following reception.

TITLE OF THE INVENTION

Method at OFDM-reception for correction of frequency,
time window, sampling clock and slow phase variations.

TECHNICAL FIELD

The present invention relates to a method at digital
system for correction of frequency, sampling clock and
phase error which varies slowly with time, i.e. low-
frequency phase noise. The receiver is a so called OFDM-
receiver which receives digital information in frames.

PRIOR ART

OFDM (Orthogonal Frequency Division Multiplex) is a type
of modulation where a digital signal is multiplexed on
many narrow-band carriers. The narrow-band carriers are
packed with high density because one utilizes the fact
that the carriers are orthogonal when the carrier
separation is equal to 1 divided by the symbol lenght
for rectangular symbols. The implementation of OFDM is
usually made by means of special circuits which perform
FFT (Fast Fourier Transform). At OFDM-signalling,
channel coding and so called soft decoding (for instance
Viterbi-decoding) is usually used in order to reduce the
probability of error and make it possible to deal with
frequency selective fading. OFDM combined with the
mentioned channel coding is called COFDM (Coded
Orthogonal Frequency Division Multiplex). System using
this form of signalling have of recent years been
implemented for different types of broadcasting, i.e.
one-way systems for digital broadcasting and for digital
TV.

The Patent document EP 448 493 describes a system for transmission of TV digitally. The picture information is transmitted to a mobile user and is divided into two parts; one is used to recreate a normal TV-picture and
5   the other together with the first one to create a larger picture. In the document EP 441 732 is described a receiver for digital radio signals. The receiver utilizes a window method to minimize the intersymbol interference arising at multipath propagation. In order
10 to reduce the negative effects at the loss of the orthogonality of the carriers at the reception, the receiver will be equipped with a time window module which is used to extract usable samples from the received signal.
15

The American document US 5 228 025 describes a method to transmit digital data via radio, preferably to mobile receivers. The method transmits a synchronization sequence in the form of at least one frequency which
20 varies in one for the receiver known way. At the receiver the synchronization sequence is utilized for tuning the local oscillator.

In the first prototype for transmission and reception of
25 DAB (Digital Audio Broadcasting) two sync symbols are used. The first is called zero symbol and contains nothing but is used by the receiver on one hand for symbol synchronization, and on the other for estimation of interference in the channel. The second symbol
30 consists of a so called chirp or sine sweep signal which is a sine shaped signal, the frequency of which changes linearly with time and which sweeeps over the whole channel width. This is used by the receiver on one hand for adjustment of the location of the time window, i.e.
35 division of the received signal in segments which are each processed by means of FFT, and on the other for

estimation of the transmission function of the channel
and estimation of deviations in the carrier frequency,
if any. In the final DAB-specification the chirp symbol
has been replaced by a so called TFPC-signal (Time
5   Frequency Phase Control), also called CAZAC-symbol,
which is used by the receiver both for timing, frequency
adjustment and for estimation of the transmission
function.

10

DESCRIPTION OF THE INVENTION/TECHNICAL PROBLEM

Transmission of information by means of OFDM-technology
makes quite different demands upon accuracy than in
15 conventional systems. The normal synchronization which
takes place between transmitter and receiver in
conventional broadcasting systems is at transmission of
program information in digital form with COFDM not
sufficient. There is, accordingly, a need for accurate
20 estimation of frequency, time window, sampling clock and
compensation of phase noise.

THE SOLUTION

25

The present invention relates to a method for correction
of frequency, time window, sampling clock and time
variable phase error at OFDM-reception. One from a
transmitter transmitted signal is received by the OFDM-
30 receiver. The signal, which is divided into consecutive
frames, which each in its turn is divided into symbols,
contains with certains intervals reference symbols with
a predetermined content. Each frame is divided into a
number of symbols which regarding time follow each
35 other. Respective symbol is allotted a serial number,
and the mentioned reference symbols are preferably

transmitted in pairs. The receiver analyzes the
different reference symbols. The signals in the
reference symbols consist of so called chirp signals,
i.e. so called sine sweeep signals which are sine

5   signals the frequency of which is linearly changed with
the time and which sweeps over the whole channel width.
One of the chirp signals goes from the highest frequency
to the lowest in time, and the other chirp signal from
the lowest freq   o the highest frequency. The

10   relation between t.   ontents of the reference symbols
in pair regarding time and frequency is utilized for
adjustment of the frequency of the receiver. Further,
the impulse response is calculated from the signals of
the received reference frames at which correction of

15   time window and sampling clock can be performed. The
main focus of the impulse response is determined, at
which the real position of the time window can be
determined. By means of the obtained result the position
of the time window is adjusted in relation to wished

20   position by the sampling clock being adjusted in
relation to the difference between the mentioned main
focus and wished position. Each symbol consists of a
number of superimposed carriers with among themselves
different frequencies. For each of the carriers further

25   is arranged that its phase and amplitude, which can also
be described by its real and imaginary part, is
modulated by the data information which shall be
transmitted. The mentioned real and imaginary parts are
allotted a definite position in a matrix system. In the

30   matrix system real and imaginary parts are allowed to
take different positions which are accepted. The
relation between the point which is indicated by
received real and imaginary part and the ideal position
in the matrix indicates an angle difference to the ideal

35   position which is utilized for correction of the phase
error at reception.

ADVANTAGES

The indicated method gives a possibility to make
accurate adjustments of the receiver in a way which has
5   not previously been possible and which gives increased
robustness at OFDM-reception. The method further allows
that the necessary adjustments in the receiver are
possible to perform in a simple way. The method thus
allows that the program transmission can be performed
10 with the high precision which is expected in these
connections.

DESCRIPTION OF FIGURES

15

Figure 1 shows schematically how the receiver at first
locates the chirp signals by means of a set of binary
correlators and after that precision adjusts time
window, carrier frequency and phase according to the
20 invention.

Figure 2 shows how the OFDM-signal is created by means
of IFFT (Invers Fast Fourier Transform). Each entry on
the IFFT corresponds to a carrier.

25

Figure 3 shows the matrix for estimation of phase error
with points according to the 16QAM-system and
illustrates the angle relation between the real position
of the received vector and the ideal position.

30

DETAILED EMBODIMENT

A signal sequence is transmitted from a transmitter and
35 received by a receiver. The signal sequence comprises a
number of symbols which are arranged to a frame. At the

beginning of each frame one or more synchronization
symbols are arranged. At least two of the mentioned
synchronization frames contain so called chirp signals.
A chirp signal is a sine signal the frequency of which

5   is changed linearly with time. In order to detect the
position of the ch   .gnal a set of correlators are
used. The auto corre·   for a chirp signal has a very
acute maximum. In the   ·er the symbol bit of the
chirp signal is receiveᵤ   ᵢs compared with a stored

10 signal. The signal is compared by being processed
through a number of XNOR-gates. The number of equal
bits, i.e. the hamming weight of the resulting vector is
obtained as an output signal from the correlator. The
synchronization signals which at that are obtained in 1

15 in Figure 1 are brought back to a frame structure
generator, 2 in Figure 1, which controls division of the
incoming signal in frames and symbols, and numbers the
individual samples within each symbol. The frame
structure generator in this way controls the division of

20 the signal in appropriate time windows to the FFT (Fast
Fourier Transform). The symbols coming out from the FFT
are after that forwarded to among other things a signal
processor, 3 in Figure 1, where correction values for
carrier frequency and the frequency of the sampling

25 clocks is calculated. The transmitted signal from the
transmitter has been created by means of an IFFT
(Inverse Fast Fourier Transform) according to Figure 2.
For an up-chirp signal each of the carriers has been
given an amplitude and phase according to he formula

30 $e^{j\pi k^2/N}$, where k corresponds to the number of the
carrier, and N the number of carriers. A down-chirp
signal is created in a similar way but with negative
phase; consequently the formula becomes $e^{-j\pi k^2/N}$. The
received signal is made subject to a Fast Fourier
Transform (FFT) in the receiver. The correction

35 Transform (FFT) in the receiver. The correction

calculations which are performed in unit 3 in Figure 1
implies that a multiplication by the for the carrier
allotted inverse angle is performed by received up-chirp
being multiplied by an ideal down-chirp, and that
5   received down-chirp is multiplied with an ideal up-
chirp. The in this way obtained signals, which we call
de-rotated chirps, each constitutes an estimate of the
transmission function of the channel. For an ideal
channel these estimates become equal to 1 for all
10   carriers. If a shift of the carrier frequency has
occurred somewhere in the channel, the de-rotated chirps
will have a remaining phase shift which is linearly
depending on the serial number of the carrier. The
changes get different symbols in the up- and the down-
15   chirp. The phase positions of the de-rotated chirps are
also influenced by frequency selective fading and by
wrong setting of the time window, but this influence has
the same symbol in both chirps. Therefore the carrier
error can be extracted by subtraction of the de-rotated
20   phase positions of one of the chirps from the other.
Then the influence of the carrier error is doubled,
whereas other influence is eliminated. The numerical
value of the carrier error can in one in itself known
way be estimated from the phase position´s linear
25   depending on the carrier number. The obtained number is
after that utilized in an in itself known way to correct
the frequency.

The impulse response of the channel is obtained by an
30   IFFT-transform on the de-rotated chirps. In order to
reduce the influence of the noise on the main focus
calculation the impulse response is multiplied with a
weighting function before the position of the main focus
is calculated. The difference between this position and
35   a predetermined wished position constitutes a correction
signal which after filtering controls the

clock-frequency of the A/D-converter, at which the
correction value successively will be adjusted towards
zero. Consequently the time window will land up in
wished position.

5

The impulse of the channel can be estimated
both from up-chirp and down-chirp. It is to
advantage to sum of these two estimates at the
main focus calculate because an error in carrier
10   frequency will influence the position of the main focus
with different symbols depending on whether it is
calculated on an up-chirp or on a down-chirp. The main
focus position of the sum of the two impulse responses
will therefore be insensible to errors in carrier
15   frequency because the error will neutralize itself.

The received carriers are arranged in a matrix system
with respect to their imaginary respective real part.
These points are in the complex number plan allotted an
20   area within which they are allowed to exist. A point in
the complex number plan which occur within the mentioned
area is regarded to symbolize a certain transmitted data
sequence. The relation of the point to the ideal
position indicates an angle relation between the ideal
25   position and the real position. The mentioned angle
difference indicates the phase error in the reception.
The average of the angle differences calculated from all
the different carriers in the same symbol constitutes an
estimate of the phase error. The in this way obtained
30   phase error can after that be combined with previously
obtained phase errors and be utilized for phase
correction of all carriers in the symbol in question,
and for estimation of the expected phase error at the
reception of next symbol. It can also be used for
35   estimation of small frequency deviations because these

give rise to phase errors with constant change from
symbol to symbol.

The mentioned method for estimation of the phase error
5   can be further developed in different ways. Two
different improvements of the method have been
identified. One or both improvements can be applied.

The first improvement is based on the fact that the
10 amplitude of the received signal on one and the same
occasion can be of different strength for different
carriers, frequencies. This is due to interference from
reflections of the signal, so called multipath
propagation, or interference from other transmitters
15 which transmits the same signal in a so called single
frequency network. The carriers which are subject to
destructive interference are weakened and get a worse
signal/noise-relation than the other. The frequency
depending transmission function for the channel can be
20 calculated in the receiver by analysis of the received
chirps. At calculation of the average of the angle
differences the values from the different carriers can
be weighted with the calculated transmission function at
which angle differences from carriers with high
25 attenuation in the channel is given a lower weight than
those with low attentuation. The strong noise from the
attenuated carriers can by that be made to have a
minimal influence on the estimation of the phase error.

30 The second improvement is based on the fact that one and
the same noise effect in the received signal gives
different uncertainty in the estimation of the phase
error for signals far from or close to the origin of
coordinates. In order to bridge this state of things the
35 mentioned angle relations are weighed in relation to the
distance to the origin of coordinates.

The invention is not restricred to the above as example
shown embodiment but may be subject to modifications
within the frame for the following patent claims and
5   idea of invention.

PATENT CLAIMS

1. Method at OFDM-demodulation for correction of carrier
frequency, phase error, time window and frequency of
5   sampling clock, at which one at the OFDM-receiver
received signal is divided into symbols and at defined
intervals is allotted symbols and on defined intervals
are allotted reference symbols with a predetermined
content, and the signal comprises a number of carriers
10   where each carrier is allotted a serial number and the
reference symbols can be transmitted in pairs,
c h a r a c t e r i z e d in that the received reference
symbols are analysed in the receiver, that the contents
of the received reference symbols with respect to time
15   and frequency indicate how the carrier frequency in the
receiver shall be adjusted, that the impulse response of
the channel is calculated from the signals of the
reference symbols at which correction of the time window
and the frequency of the sampling clock is performed,
20   that the position of the complex vectors of the received
demodulated carriers is compared with an ideal position
at which deviation from the mentioned ideal position is
utilized for correction of the phase error at the
reception.
25

2. Method according to patent claim 1,
c h a r a c t e r i z e d in that the position of the
complex vectors of the received demodulated carriers are
arranged in a matrix system with respect to their
30   imaginary respective real part, that each vector is
allotted an area within which it is indicated to exist,
and that a vector occurring within mentioned area is at
a certain angle distance from the ideal position, and
that the mentioned angle distance is utilized for
35   calculation of the phase error.

3. Method according to any of the previous patent
claims, c h a r a c t e r i z e d in that the amplitude
of the received signal is different in strength for
different carriers depending on whether the receiver
5   receives more signals, that the phase error estimation
for respective carrier is weighted depending on the
amplitude of the transmitting function at current
frequency, at which a signal with higher amplitude is
given a higher weighting than a signal with lower
10   amplitude.

4. Method according to any of the previous patent
claims, c h a r a c t e r i z e d in that the vectors
depending on their amplitude, i.e. their distances from
15   the origin of coordinates, are given different weights,
which weights compensate for the amplitude depending
influence of the noise on the angle error, at which the
angle distance farthest away from the origin of
coordinates is allotted a higher weighting than those
20   which are close to the origin of coordinates, and that a
correction of the phase error is performed corresponding
to the weighted angle error.

5. Method according to any of the previous patent
25   claims, c h a r a c t e r i z e d in that the latest
obtained phase error is compared with previously
obtained phase error and that the expected phase error
at reception of next sequence is calculated.

30   6. Method according to any of the previous patent
claims, c h a r a c t e r i z e d in that the position
of the main focus of the impulse response of the channel
is determined, which position indicates the real
position of the time window, and that the position of
35   the time window is adjusted in relation to the
difference between real position and wanted position by

the frequency of the sampling clock being adjusted in
relation to the mentioned difference.

7. Method according to any of the previous patent
5   claims, c h a r a c t e r i z e d in that amplitude and
phase of the carriers in the reference symbols are
related to the frequency of respective carrier.

8. Method according to any of the previous patent
10   claims, c h a r a c t e r i z e d in that the contents
of the reference symbols consist of chirp signals.

9. Method according to any of the previous patent
claims, c h a r a c t e r i z e d in that the reference
15   symbols are transmitted in pairs at which the reference
symbols in pairs are allotted one a up-chirp and the
other a down-chirp.

10. Method according to any of the previous patent
20   claims, c h a r a c t e r i z e d in that amplitude and
phase of the carriers in the up-chirps is defined by
$e^{j\pi k^2/N}$ and in the down-chirps by $e^{-j\pi k^2/N}$, where N
represents the number of carriers, k the serial number
of respective carrier, and $j^2 = -1$.

AMENDED CLAIMS
[received by the International Bureau on 19 April 1996 (19.04.96);
original claims 1-10 replaced by amended claims 1-7 (2 pages)]

1. Method at OFDM-demodulation for correcting of carrier frequency,
phase error, time window and frequency of sampling clock, at which
one at the OFDM-receiver received signal is divided into symbols and
at defined intervals is allotted symbols and on defined intervals are
allotted reference symbols with a predetermined content, and the
signal comprised a number of carriers where each carrier is allotted a
serial number and the reference symbols can be transmitted in pairs,
the received reference symbols are analysed in the receiver, and the
contents of the received reference symbols with respect to time and
frequency indicate how the carrier frequency in the receiver shall be
adjusted, the impulse response of the channel is calculated from the
signals of the reference symbols at which correction of the time
window and the frequency of the sampling clock is performed, the
position of the complex vectors of the received demodulated carriers is
compared with an ideal position at which deviation from the
mentioned ideal position is utilized for correction of the phase error at
the reception, c h a r a c t e r i z e d in that amplitude and phase of the
carriers in the reference symbols are related to the frequency of
respective carrier.

2. Method according to patent claim 1, c h a r a c t e r i z e d in that the
position of the complex vectors of the received demodulated carriers
are arranged in a matrix system with respect to their imaginary
respective real part, that each vector is allotted an area within which it
is indicated to exist, and that a vector occurring within mentioned area
is at a certain angle distance from the ideal position, and that the
mentioned angle distance is utilized for calculation of the phase error.

3. Method according to any of the previous patent claims, c h a r a c t e-
r i z e d in that the amplitude of the received signal is different in
strength for different carriers depending on whether the receiver

AMENDED SHEET (ARTICLE 19)

receives more signals, that the phase error estimation for respective carrier is weighted depending on the amplitude of the transmitting function at current frequency, at which a signal with higher amplitude is given a higher weighting than a signal with lower amplitude.

4. Method according to any of the previous patent claims, c h a r a c t e- r i z e d in that the vectors depending on their amplitude, i.e. their distances from the origin of coordinates, are given different weights, which weights compensate for the amplitude depending influence of the noise on the angle error, at which the angle distance farthest away from the origin of coordinates is allotted a higher weighting than those which are close to the origin of coordinates, and that a correction of the phase error is performed corresponding to the weithted angle error.

5. Method according to any of the previous patent claims, c h a r a c t e- r i z e d in that the latest obtained phase error is compared with previously obtained phase error and that the expected phase error at reception of next sequence is calculated.

6. Method according to any of the previous patent claims, c h a r a c t e- r i z e d in that the position of the main focus of the impulse response of the channel is determined, which position indicates the real position of the time window, and that the position of the time window is adjusted in relation to the difference between real position and wanted position by the frequency of the sampling clock being adjusted in relation to the mentioned difference.

7. Method according to any of the previous patent claims, c h a r a c t e- r i z e d in that the contents of the reference symbols consist of chirp signals.
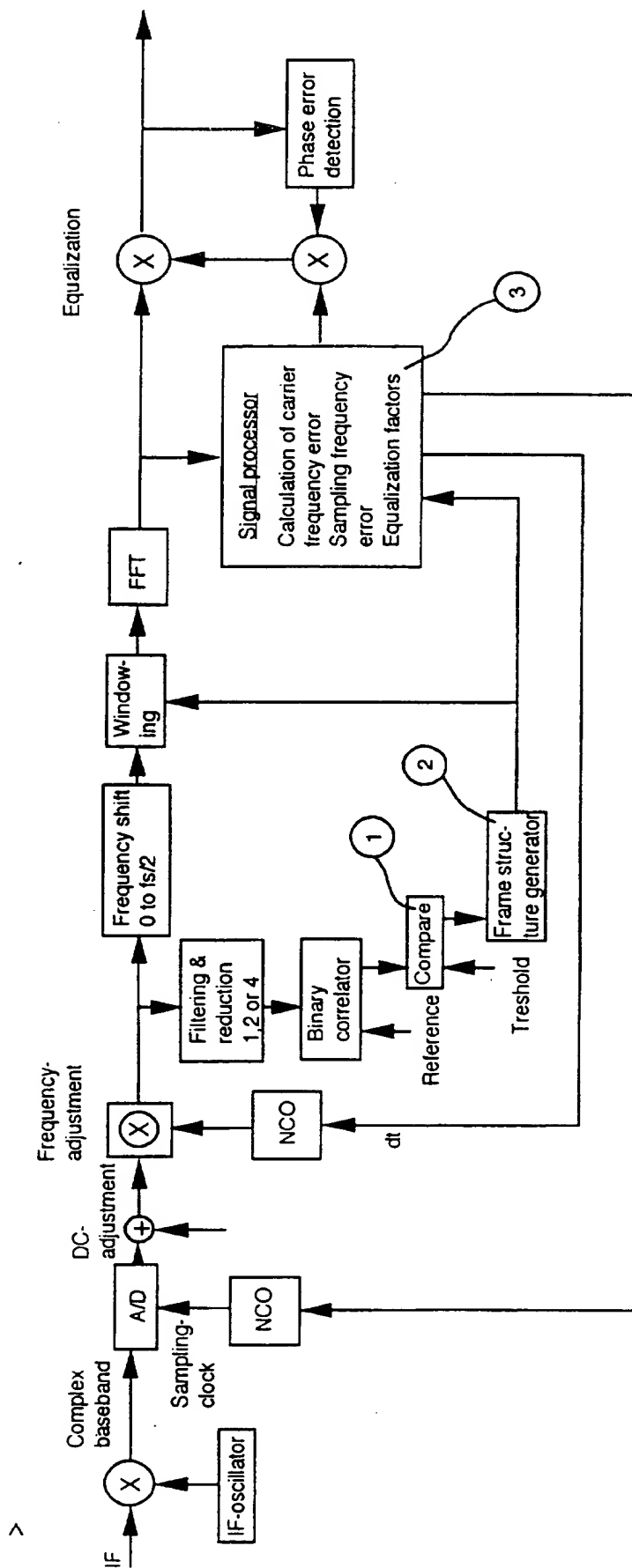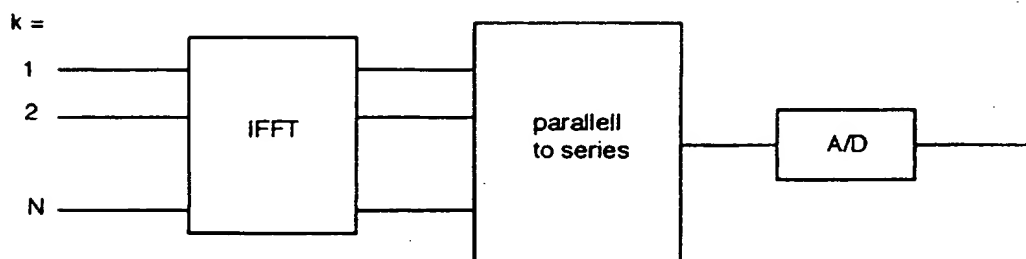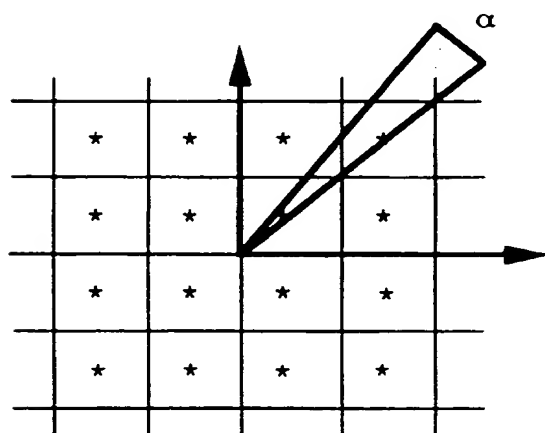
AMENDED SHEET (ARTICLE 19)

Figure 1

Figure 2

* possible transmitted signal vector

· example of received signal vector

α phase deviation for received signal vector

Figure 3

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 5/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the inter........ (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0529421 A2 (DAIMLER-BENZ AKTIENGESELLSCHAFT), 3 March 1993 (03.03.93), page 3, line 15 - line 41; page 6, line 1 - line 8; page 8, line 6 - line 21, abstract	1,8
Y		2,3,5
	--	
Y	US 5345440 A (J. GLEDHILL ET AL), 6 Sept 1994 (06.09.94), column 8, line 1 - column 9, line 55, figure 5	2
	--	
Y	EP 0618697 A2 (GRUNDIG E.M.V.), 5 October 1994 (05.10.94), page 5, column 52 - column 58	3,5
	-- -------	

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 March 1996	21 -03- 1996

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Göran Magnusson Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

International application No.
PCT/SE 95/01413

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A2- 0529421	03/03/93	DE-A-	4128713	04/03/93
US-A- 5345440	06/09/94	AU-B-	646298	17/02/94
		AU-B-	651818	04/08/94
		AU-A-	7584591	30/10/91
		AU-A-	8613691	15/04/92
		EP-A-	0521995	13/01/93
		EP-A-	0548205	30/06/93
		JP-T-	5505290	05/08/93
		JP-T-	6501357	10/02/94
		WO-A-	9115925	17/10/91
		WO-A-	9205646	02/04/92
		AU-A-	1173492	27/08/92
		WO-A-	9212792	06/08/92
EP-A2- 0618697	05/10/94	NONE		

BLANK PAGE